Monitoring Methodology for Assessing the Impact of Forest Herbicide Use on Small Mammal Populations in British Columbia

by
Chris Ritchie[1] and Thomas P. Sullivan[2]

[1] Ritchie Environmental Consulting
517 W 15th Street
North Vancouver, B.C. V7M 1S8

[2] Applied Mammal Research Institute
23523 47th Avenue
Langley, B.C. V3A 4R1

June 1989

ECONOMIC & REGIONAL DEVELOPMENT AGREEMENT

Canada

BC

90-01252/

Funding for this publication was provided by the Canada-British Columbia Forest Resource Development Agreement - a five year (1985-90) $300 million program cost-shared equally by the federal and provincial governments.

Canadian Cataloguing in Publication Data

Ritchie, Chris
Monitoring methodology for assessing the impact of forest herbicide use on small mammal populations in British Columbia

(FRDA report, ISSN 0835-0752 ; 081)

Issued under Canada-BC Forest Resource Development Agreement.
Co-published by B.C. Ministry of Forests.
"Canada/BC Economic & Regional Development Agreement."
Bilbliography: p.
ISBN 0-7726-0966-7

1. Rodents – British Columbia – Effect of herbicides on. 2. Rodents – British Columbia – Effect of habitat modification on. 3. Herbicides – Environmental aspects – British Columbia. I. Sullivan, Thomas Priestlay, 1951 - . II. Canada. Forestry Canada. III. British Columbia. Ministry of Forests. IV. Canada-British Columbia Forest Resource Development Agreement. V. Canada/BC Economic & Regional Development Agreement. VI. Title. VII. Series.

QL737.R6R57 1989 599.32'30452642 C89-092160-1

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This is a joint publication of Forestry Canada and the British Columbia Ministry of Forests.

Produced and distributed by the Ministry of Forests, Research Branch.

For additional copies and/or further information about the Canada-British Columbia Forest Resource Development Agreement, contact:

Forestry Canada
Pacific Forestry Centre
506 West Burnside Road
Victoria, B.C. V8Z 1M5
(604) 388-0600

or

B.C. Ministry of Forests
Research Branch
31 Bastion Square
Victoria, B.C. V8W 3E7
(604) 387-6719

ABSTRACT

Several small mammals were identified as useful target species to monitor herbicide impacts in the Coastal Western Hemlock Biogeoclimatic Zone on Vancouver Island and the coastal mainland, and in the Sub-Boreal Spruce Biogeoclimatic Zone. Target biogeoclimatic subzones were also identified. Because of the variability within small mammal populations, intensive monitoring is the only objective and rigorous method to assess potential impacts from habitat alteration. A method for vegetation monitoring is also presented. Further research is required on vegetation response to herbicides, small mammal use of herbicide-treated vegetation, and furbearer response to habitat alteration and changes in small mammal populations.

Key Words: small mammals, herbicide use, monitoring, live-trapping, index lines, grids, populations, pellet transects, forest plantations, vegetation management.

ACKNOWLEDGEMENTS

We thank Forestry Canada and the B.C. Ministry of Forests for financial support, under the Forest Resource Development Agreement (FRDA). We are grateful for the co-operation of various research and field personnel who were contacted during the preparation of this document.

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1 INTRODUCTION

In British Columbia, herbicides are used in intensive forest management to reduce competition between deciduous vegetation and coniferous species (Biggs and Walmsley 1988). Herbicide use has accelerated in recent years, increasing fourfold between 1983 and 1985, and this increase is expected to continue (Von Schuckmann 1986).

Herbicide use is directed at the early seral stages of forest succession. Several species of small mammals use these habitats for forage and cover (Banfield 1974; Maser *et al.* 1981), and are important prey for furbearers and avian predators. Habitat alteration resulting from herbicide application could result in changes to small mammal species abundance and diversity.

Several studies have identified the need to monitor the impact of herbicide use on small mammal populations (Pollack *et al.* 1986; Biggs and Walmsley 1988). Appendix 1 summarizes the results of 10 published studies measuring the response of small mammal populations to herbicide-induced habitat alteration. Despite a range of forest types and census methods, several trends have emerged from these data. In 9 of 10 studies, deer mouse (*Peromyscus maniculatus*) abundance has increased or remained constant in treatment areas compared to control areas. Voles (genera *Microtus* and/or *Clethrionomys* depending on study) declined in four of eight studies and increased or showed little change in the other four reports. Where counted, chipmunks (*Eutamias* spp.) were little affected by habitat alteration. Shrews showed a mixed response dependent on species in two studies, and increased or remained unchanged in the other cases. Perhaps the most relevant measurement was that forest herbicide treatment resulted in an increase or no change for the total number of small mammals in eight of nine studies.

In addition to the variability of species responses is the lack of transferability of research results between ecological settings. These factors highlight the need for specific small mammal species to be studied in their ecological settings within British Columbia. Such case studies would help researchers identify and quantify the impacts of forest herbicide use on small mammal populations.

The objective of this report was to develop a strategic approach for monitoring such impacts. The report identifies target small mammal species and biogeoclimatic subzones on which to concentrate monitoring of herbicide impacts. It also presents a methodology to conduct monitoring activity, and identifies associated expertise requirements.

2 MONITORING RATIONALE

Small mammals are generally secretive and essentially impossible to observe directly. Thus, they are usually sampled by trapping, which allows collection of sex, age, reproductive, and other demographic attributes of the population. Trapping also provides a method of density estimation. Larger small mammals, such as the snowshoe hare, may be directly counted by night-lighting, but this method only provides numbers observed. Counts of sign, such as fecal pellets or tracks, may also be used. These latter counts may be useful for species such as the snowshoe hare, but not for small rodents.

Both live-traps and kill-traps are used to sample small mammal populations. Kill-trapping provides a static sample for a given point in time, but if repeated on the same area, it may not provide an accurate sample of the population. It has been conventional wisdom that kill-trapping once or twice a year for short periods has little impact on rodent populations. However, there is now considerable evidence (Metzgar 1971; Mihok 1979; Webster and Brooks 1981; Clulow *et al.* 1982; Jannet 1982) that many rodents have a well-developed social structure. Removal of some individuals, particularly important reproductive members of a population, may alter subsequent breeding patterns, age structure, and behaviour among young and females (Van Horne 1981). In addition, kill-traps operated for more than three consecutive 24-hour periods may attract non-resident animals into the sampling area (Southern 1965; Johnson and Keller 1983).

Live-trapping provides a dynamic sample which follows a population through time. The collection of time-series data for small mammals permits analysis of the effects of a perturbation, such as habitat alteration, on the demographic characteristics of a specific population. Such characteristics may change

from season to season and year to year. Thus, it is essential to have continuity in the sampled populations to assess accurately and rigorously the potential effects of herbicide use.

The most complete and reliable determination of population patterns comes from live-trapping at regular intervals through time. Trapping once per year yields only a minimum or maximum with no reference point in time to make comparisons. Repeated trapping within a given year records seasonal changes in population parameters, and provides a dynamic series of samples. Timing of samples should recognize seasonal breeding patterns associated with latitude and precipitation. In turn, trapping duration within a sampling period is a compromise between long enough for maximum trap exposure for residents, but short enough to neither attract transients, nor stress animals from prolonged confinement.

Monitoring small mammal populations by an index line of traps is the simplest method of live-trapping for comparing differences in abundance between seasons, years, and areas (Linn 1963; Southern 1965; Petticrew and Sadleir 1970; Linn and Downton 1975). Index lines provide the minimum inventory information, such as relative species occurrence and abundance, and reproductive patterns. Unless checked against a grid (area) trapping system, index lines will not provide density estimates. However, when these assessments have been done, comparable and reliable estimates are obtained (Petticrew and Sadleir 1970; Smith *et al.* 1975; O'Farrell and Austin 1978; Sullivan and Sullivan 1983).

A grid system of traps is the most effective method for monitoring all demographic parameters of various populations on a unit area. It provides a greater probability of an animal encountering a trap and being captured. Thus, a grid may provide a more representative sample of all species, both common and rare, living in a given area than would a line of traps. Density estimates are readily obtained and may be compared between different areas, seasons, and years.

The number of combinations of trapping type, duration, and intensity is large. Choice of sampling regime depends on the accuracy and type of results required and the amount of resources available to conduct sampling.

3 METHODS

This report is based on a review of the literature in the field of vegetation management, forest herbicides, and small mammals, and on discussions with key researchers in these fields. In addition, regional staff from the Ministry of Forests and Lands and the Ministry of Environment and Parks (now the Ministry of Forests and Ministry of Environment, respectively), and individuals from the forest industry and the B.C. Trappers' Association were contacted.

Most of the research on small mammal ecology has been conducted outside British Columbia. This meant that research from other regions had to be extrapolated to fit conditions in this province. As a result, habitat use and food utilization are often identified only in general terms. In addition, research on the effects of herbicide use on small mammals and non-target vegetation is scarce. Therefore, small mammal response to various forms of habitat manipulation was used to anticipate impacts from herbicide treatment.

3.1 Target Small Mammal Species

Selection of small mammal species for monitoring the effects of herbicide use was based on three criteria. Each species should:

1. *occur throughout either the Sub-Boreal Spruce (SBS) or Coastal Western Hemock (CWH) biogeoclimatic zones.* These two zones account for 73.7% of total herbicide use in British Columbia (Biggs and Walmsley 1988). Herbicide use in these zones has the greatest potential to affect small mammal populations. Species with restricted ranges in these zones are less useful for monitoring than are those with extensive ranges.
2. *use habitats subject to broadcast herbicide treatment.* Herbicide treatment will concentrate on early successional stages, 2-15 years post-logging, dominated by deciduous vegetation (Biggs and Walmsley 1988). Herbicides will be used to shorten the brush-dominated stage of succession. This change results in alteration of a habitat type which supports diverse small mammal communities (Maser *et al.* 1981). Broadcast herbicide application can affect all

vegetation on a site. It has the potential for the largest habitat alteration, and therefore the greatest potential to affect small mammal populations.

3. *occur in the furbearer diet.* A major concern for changes in small mammal populations relates to their role as prey species (Biggs and Walmsley 1988). Many furbearing species rely on small mammals as an important component of their diet (Banfield 1974). Thus, changes to small mammal populations may affect furbearing species.

3.2 Target Biogeoclimatic Zones

Selection of target biogeoclimatic subzones was also based on several criteria. A target subzone should:

1. *receive considerable herbicide use.* Herbicide use may concentrate on specific subzones. Impacts on small mammal populations are likely to be greatest in these subzones, and are therefore more deserving of study than those receiving minor herbicide treatment.
2. *support complex assemblages of vegetative species.* Sites that support vegetation providing dense cover and food are valuable to small mammals. In addition, they are often very productive timber-producing sites (Pollack *et al.* 1986) and so are valuable to the forester. Plant species providing food and cover for small mammals, as well as those with high browse values (important to snowshoe hare (*Lepus americanus*)), are typically found in moist, rich, disturbed sites (Haeussler and Coates 1986).
3. *represent a significant portion of the zone.* Monitoring subzones with wide distribution and large geographic extent will provide information on a larger portion of the biogeoclimatic zone than that provided by a restricted subzone.

A final consideration, when choosing actual monitoring locations, is the proximity of water. All bodies of water, and their tributaries, that support fish are protected by a 10-m pesticide-free zone (Von Schuckmann 1986). This zone reduces the risk of introducing toxic substances to fish habitat, and reduces habitat degradation due to erosion or overheating. It also reduces the impact of herbicide application on terrestrial species living in or near the zone. This factor must be considered during evaluation of monitoring results from this habitat.

4 RESULTS AND DISCUSSION

4.1 Target Small Mammal Species

The CWH zone on Vancouver Island

The CWH biogeoclimatic zone is found on Vancouver Island and on the coastal mainland. Small mammal communities are similar in both areas, but species diversity is higher on the mainland (Table 1).

Small mammal species best suited for monitoring on Vancouver Island are the deer mouse and the Townsend vole (*Microtus townsendii*). Both species are important prey items for furbearers (Rue 1981) and both occur throughout Vancouver Island (Cowan and Guiguet 1956). The deer mouse is often the first species to increase in abundance on disturbed sites (Tevis 1956; Hooven and Black 1976) and initially may be the only species present (Halvorson 1982). Deer mice have a diverse diet, but feed primarily on seeds, insects and berries (Green 1979; Martell and Macaulay 1981). *Peromyscus* spp. display annual cycles of population abundance (Sullivan 1979, 1980).

The Townsend vole prefers moist grassy habitats (Hawes 1975; Getz 1985), where it feeds on grasses and sedges (Maser and Storm 1970; Whitaker 1980). Increase in vole abundance may be delayed if this vegetation is lacking (Sims and Buckner 1973). *Microtus* spp., including the Townsend vole, may display multi-year cycles of abundance (Krebs and Myers 1974), which may confound interpretation of treatment effects. Therefore, caution is required when *Microtus* is used as a target species. Both species can be monitored with the same sampling program (Sullivan 1982; Sullivan and Sullivan 1982a; Sullivan 1989).

Other species present in the CWH zone are less valuable for monitoring purposes because: they are not important foods of furbearers (e.g., *Sorex* spp.) (Ingles 1965; Ables 1975; Gier 1975; Erlinge 1981); or they have a restricted range within the zone (Cowan and Guiguet 1956); or they make minimal use of habitats subject to broadcast herbicide application (Maser *et al.* 1981) (Table 1).

TABLE 1. Small mammal species of the Coastal Western Hemlock and Sub-Boreal Spruce biogeoclimatic zones of British Columbia[a]

	Coastal Western Hemlock		Sub-Boreal Spruce
	Vancouver Island	Mainland	
Sorex cinereus	—	P3	P3
Sorex monticolus	P3	P3	P3
Sorex palustris	P2,3	P2,3	P3
Sorex vagrans	P3	P3	P3
Microsorex hoyi	—	—	P3
Lepus americanus	—	T4	T
Ochotona princeps	—	P2	P2
Aplodontia rufa	—	P1	—
Tamiasciurus hudsonicus	P2	P2	P2
Tamiasciurus douglasii	—	P2	—
Glaucomys sabrinus	—	P2	P2
Eutamias amoenus	—	T	T
Eutamias townsendii	—	P1	—
Marmota monax	—	—	P2,3
Peromyscus maniculatus	T	T	T
Neotoma cinerea	—	P2	P2
Clethrionomys gapperi	—	T	T
Phenacomys intermedius	—	P1	P1
Microtus longicaudus	—	T	P1,4
Microtus pennsylvanicus	—	—	T
Microtus townsendii	T	P1	—
Microtus oregoni	—	P1	—
Ondatra zibethica	P2	P1,2	P2
Rattus rattus	—	P1	—
Zapus hudsonicus	—	—	T
Zapus princeps	—	P1	T
Zapus trinotatus	—	P1	—

[a] T=target species, P=species present, —=species absent, [1]=minor presence in zone, [2]=minor use of early successional habitats, [3]=minor use by furbearers, [4]=see text.

The CWH zone on the coastal mainland

In the mainland CWH zone, target species include: the deer mouse, long-tailed vole (*M. longicaudus*), northwestern chipmunk (*Eutamias amoenus*), and boreal red-backed vole (*Clethrionomys gapperi*). Each of these species is an important component of the furbearer diet (Banfield 1974) and occurs extensively in the CWH zone (Cowan and Guiguet 1956).

The long-tailed vole is similar to the Townsend vole, but may occur in more brushy shrub habitat (Hawes 1975; Randall and Johnson 1979; Getz 1985), where it feeds primarily on green vegetation (Maser *et al.* 1981). The northwestern chipmunk also prefers brushy habitat (Hooven and Black 1976; Sharples 1983) and feeds on a wide variety of fruits, flowers, seeds, and fungi (Woods 1980). These habitat preferences often delay increases in abundance following site disturbance (Tevis 1956; Hooven and Black 1976).

The red-backed vole is a key prey species of the marten (*Martes americana*) (Cowan and MacKay 1950; Soutiere 1979). This vole feeds on lichens, fungi, green plant material, and seeds (Whitaker 1980; Martell 1981). The red-backed vole prefers mature forest habitat (Martell and Radvanyi 1977), but will persist following clearcutting if sufficient cover remains (Martell 1983). The strong affinity of the red-backed vole for cover may increase its sensitivity to habitat alteration, especially in mid-successional stages. Both vole species can demonstrate 3- to 4-year cycles in abundance (Banfield 1974; Green 1979), while *Eutamias* spp. display annual cycles (Sullivan *et al.* 1983).

All four species can be monitored with the same sampling program (Sullivan 1989). The relative importance of each target species changes as early seral vegetation matures. Deer mice are the most useful species to monitor in herb stages, while long-tailed voles and northwestern chipmunks are more important in intermediate vegetation stages (herb-shrub). Red-backed voles may be important to monitor at all stages, but especially in mature shrub and coniferous stands.

Another important prey species in the CWH zone on the mainland is the snowshoe hare. It is the primary prey of the lynx (*Lynx canadensis*) (Parker *et al.* 1983), but is also important to other furbearers (Rue 1981). The snowshoe hare prefers habitat with dense vegetative cover (Sullivan and Moses 1986). Woody deciduous vegetation provides it with forage in winter (Fox 1978; Parker 1984) and concealment from predators in summer (Conroy *et al.* 1979; Wolfe *et al.* 1982). Reliance on brushy vegetation, typical of early successional stages, increases the snowshoe hare's sensitivity to habitat alteration (Sullivan and Moses 1986).

These factors suggest the snowshoe hare as a good target species. However, hares require a different monitoring strategy. The snowshoe hare is a larger mammal, with a larger home range than that of the other target species. These factors necessitate the use of different traps and trapping areas. The snowshoe hare also displays 9- to 10-year population cycles, with dramatic changes in abundance (Keith 1963; Keith and Windberg 1978). This cycle makes identification of herbicide-induced impacts more difficult. In addition, the main predator of hares, the lynx, is absent from coastal areas (Cowan and Guiguet 1956). The snowshoe hare is therefore a secondary target species in the CWH zone.

Other species are less valuable for monitoring purposes, for reasons previously stated (Table 1).

The SBS zone in north-central British Columbia

The SBS biogeoclimatic zone is situated in north-central British Columbia. Small mammal species in this zone are similar to those in the mainland CWH zone (Table 1). Species best suited for monitoring in the SBS zone include: the deer mouse, red-backed vole, meadow vole (*M. pennsylvanicus*), northwestern chipmunk, meadow jumping mouse (*Zapus hudsonicus*), western jumping mouse (*Z. princeps*), and snowshoe hare.

The meadow vole is similar to the long-tailed vole and usually replaces it in dense grassy interior habitats (Cowan and Guiguet 1956; Getz 1985). It has been studied more extensively than the long-tailed vole, and its ecology is more completely understood. Meadow voles rapidly increase in abundance on disturbed sites (Gashwiler 1970; Krefting and Ahlgren 1974), although not as quickly as deer mice (Sims and Buckner 1973). Their diet consists of grasses and sedges, with some forbs

and fruits (Maser and Storm 1970; Green 1979). The meadow vole is an important prey species for furbearers (Banfield 1974) and displays strong 3- to 4-year cycles of abundance (Green 1979).

The two species of jumping mice occur in brushy habitats, often on wet sites (Cowan and Guiguet 1956), and are prey species for several furbearers (Banfield 1974; Gier 1975). Jones *et al.* (1978) found that the western jumping mouse forages on shrub species typical of early successional stages. As in the CWH zone, deer mice are the best target species in herb stages, followed by meadow voles on older sites (shrub stages). The jumping mice and northwestern chipmunks are the best target species on intermediate-aged sites (herb-shrub stages). Again, red-backed voles are most important in mature shrub stages and coniferous stands, but may be important at all stages.

The snowshoe hare is a very important target species in the SBS zone because of the importance of lynx as a furbearer. Therefore, monitoring snowshoe hare populations in the SBS zone is more valuable than in the CWH zone. It is most important to monitor snowshoe hares in advanced successional stages (shrub-tree).

As in the CWH zone, some species found in the SBS zone are unsuited for monitoring purposes (Table 1).

While certain small mammal species can be designated as target species, difficulties may still arise because of low abundance or other factors. Improvements to our knowledge of small mammal habitat requirements may result in deletion of some target species and addition of others. Researchers should, therefore, make complete documentation of all species captured for use in future research.

4.2 Target Biogeoclimatic Zones

The subzone best suited for monitoring in the CWH biogeoclimatic zone is the "wetter" (CWHb) subzone. It is found throughout Vancouver Island, except on the southeast coast, and extensively on the coastal mainland. It is differentiated from other CWH subzones by cooler temperatures, higher precipitation, and a larger shrub community (Klinka *et al.* 1979).

Most plant species present in the mature forest are also present following logging (Dyrness 1973). Thus, areas like the CWHb subzone, which support dense shrub and herb communities in mature forests (Franklin and Dyrness 1973), will have strong shrub and herb communities on disturbed sites. These plants provide food and cover for small mammals (Maser *et al.* 1981). The CWH subzones receive herbicide treatment depending on local brush conditions. The moist character of the CWHb subzone suggests that brush competition will occur, and result in herbicide treatment.

In the SBS zone, the "very wet Rocky Mountain" (SBSf) and the "wet cool central" (SBSj) subzones are the best suited for monitoring. Both subzones are found primarily northeast of Prince George. Herbicide use will likely be concentrated in these wetter, richer SBS subzones which have well-developed shrub and herb communities (Meidinger *et al.* 1984). They are, therefore, likely to provide good habitat for small mammals.

4.3 Monitoring Methodology

4.3.1 Live-traps

If a live-trapping program is to monitor small rodents effectively, Longworth or Sherman live-traps must be used. These are designed to be left permanently in the field. Trap doors are locked open except during sampling. Longworth traps have been specifically designed for small rodents and will readily capture the majority of rodents and insectivores in a given sampling area. Several studies have used Longworth traps to capture all known resident small rodent species in coastal forests (Sullivan and Sullivan 1982a; Sullivan 1989) and in forests of the southern and central interior (Sullivan and Sullivan 1982b).Voles are particularly sensitive to confinement and must have warm and dry accommodation such as is offered in the nest box of the Longworth trap.

Sherman traps will also readily capture deer mice and chipmunks, but may not be as reliable for voles, particularly juveniles (Jett *et al.* 1986). In addition, overnight trap mortality and stress of captured animals is higher in Sherman than Longworth traps, particularly in cool, wet conditions. Live-traps for hares are large cage traps, (23 x 23 x 80 cm) which may also be locked open. To

prevent mortality of animals, all traps should be covered with a 30 x 30 cm piece of plywood (sheet of tar paper for hare traps) to protect traps from sunlight and rain.

4.3.2 Pellet transects

An alternative method for assessing the presence of snowshoe hares in a given habitat involves the use of pellet transects. To obtain estimates of habitat use, pellets are counted on a series of permanent circular plots. Individual plots of 1.8 m^2 (0.000 18 ha) are arranged in transects, with each transect consisting of 10 stations spaced at 30-m intervals. Each station has a pair of plots with centres 1.5 m on each side of the transect centre line (total of 20 plots per line).

This technique is modified after that of Wolfe *et al.* (1982). Other useful sampling designs are discussed by Conroy *et al.* (1979), Pietz and Tester (1983), and Litvaitis *et al.* (1985). Pellets should be counted and removed at the initial sampling on each transect and thereafter on a seasonal basis. Summer and winter habitat use may be distinguished by counting pellets in spring and fall each year. A total of 100 plots (five transects of 20 plots each) should be an adequate sampling intensity for each control or treatment area.

4.3.3 Trapping configuration

Live-traps may be used on index lines or grids. A common index line for mice, voles, and chipmunks uses 20 stations per line, with stations 15 m apart, and up to three traps placed within a 2-m radius of each station. For snowshoe hare, the system of Sullivan and Sullivan (1983), consisting of two parallel lines (each 300 m long and 30 m apart) with 10 traps per line, could be used.

A common grid configuration for small rodents uses a 1-ha matrix with 49 (7 x 7) stations set at 14.29-m intervals. One trap per station is normally adequate for monitoring purposes, but two traps per station should be used at high densities (>50 per hectare). This system provides density estimates for 1 ha and is an optimum size for replication, and for obtaining sample sizes of all resident small mammal species (Sullivan and Sullivan 1982a). Once established, trap grids should be set permanently in place in a given study area for the duration of the monitoring project. Index line traps could be rotated among study areas for best use of available traps.

In both grid and line trapping, a "pre-baiting" period must precede sampling. Traps are left at the site, with doors locked open, for 2-3 weeks to permit familiarization of animals to the traps. Pre-baiting allows maximum trappability of resident small mammals and is essential for capturing adequate samples of most species of voles.

4.3.4 Monitoring intensity

The most complete and reliable way to determine population patterns is to live-trap at regular intervals. For mice, voles, and chipmunks, an absolute minimum is two sampling periods. The first sampling period should occur during spring breeding in May, likely the low point of the annual population cycle. The second sampling period should occur during fall post-breeding in early October, at the high point of the cycle. This approach can provide comparative numbers, relatively undisturbed age structure, and indicate breeding status.

This approach is most suitable for index lines and can be used for small rodents and snowshoe hares. Four to six nights is a common duration for each sampling period to allow resident animals sufficient time to encounter the line of traps. Both spring and fall sampling periods should be considered independent events. A degree of continuity in population parameters is achieved only with the intensive sampling scheme discussed below.

An intensive sampling scheme would involve two-night trapping periods in 3-week intervals from May to October (total of eight trapping periods). Shorter intervals are not required to adequately record changes in density or demography. Sampling every 4 weeks is also acceptable, but longer intervals may not provide consistent trappability of animals nor accurate measurements of some parameters (Renzulli *et al.* 1980). It is important to note that the average gestation period is 3 weeks in most small rodents. This should be reflected in the sampling intensity for ongoing studies. An intensive sampling scheme for snowshoe hares would involve trapping every 4 weeks from May to October (total of six trapping periods). Longer intervals reduce trappability and reliability of density

estimates and demographic measurements. Trapping during winter (November to April) is not necessary to provide reliable population monitoring, and is usually not practical because of adverse weather conditions and difficulty of access.

Examples of results, in terms of density measurements, from an intensive sampling regime are illustrated in Figure 1 for deer mouse populations and in Figure 2 for Oregon vole populations (Sullivan 1989). Two methods of measuring density (Jolly-Seber and minimum number alive) are given (see Appendix 2).There were no significant differences in density of deer mice or voles between control and treat-ment populations over the entire study period (Sullivan 1989). However, there were significant differences between control and treatment populations during specific sampling weeks (indicated by shaded bars).

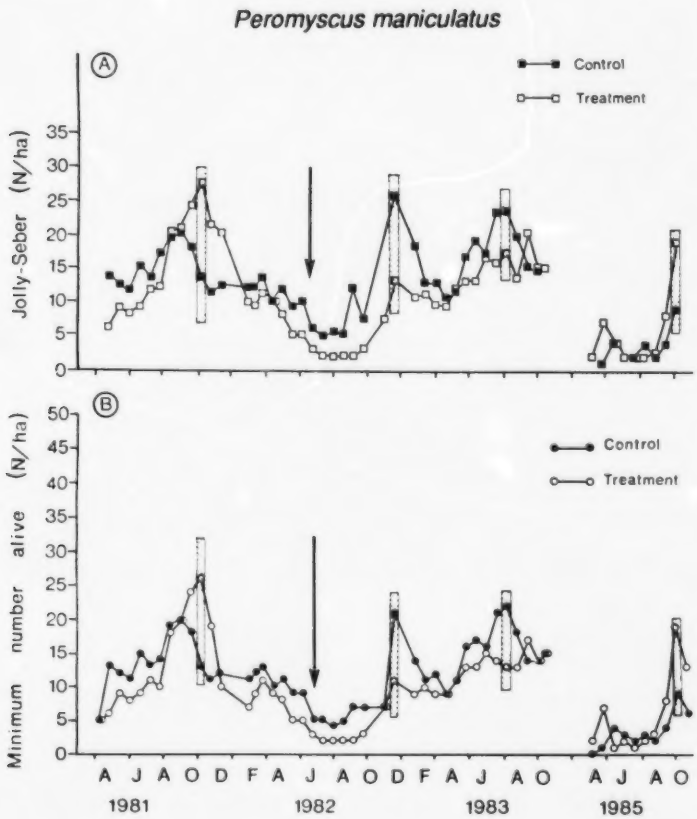

FIGURE 1. Population density (A: Jolly-Seber, B: MNA) of deer mice on control and treatment grids during 1981 to 1985. Vertical arrow indicates when glyphosate herbicide was applied to the treatment area. Shaded bars represent specific sampling periods which have significant differences in density of mice between areas.

Therefore, if a limited sampling scheme (one or two census periods per year) was used, then there is a very high probability that erroneous conclusions will be reached with respect to numbers of animals on control and treatment areas. Weekly or monthly variation in the abundance of a given species on a control or treatment area may yield a misleading result if sampling was conducted during such times. Clearly, small mammal populations vary sufficiently over time on a given area that intensive monitoring is the only objective and rigorous method to assess potential impacts from habitat alteration.

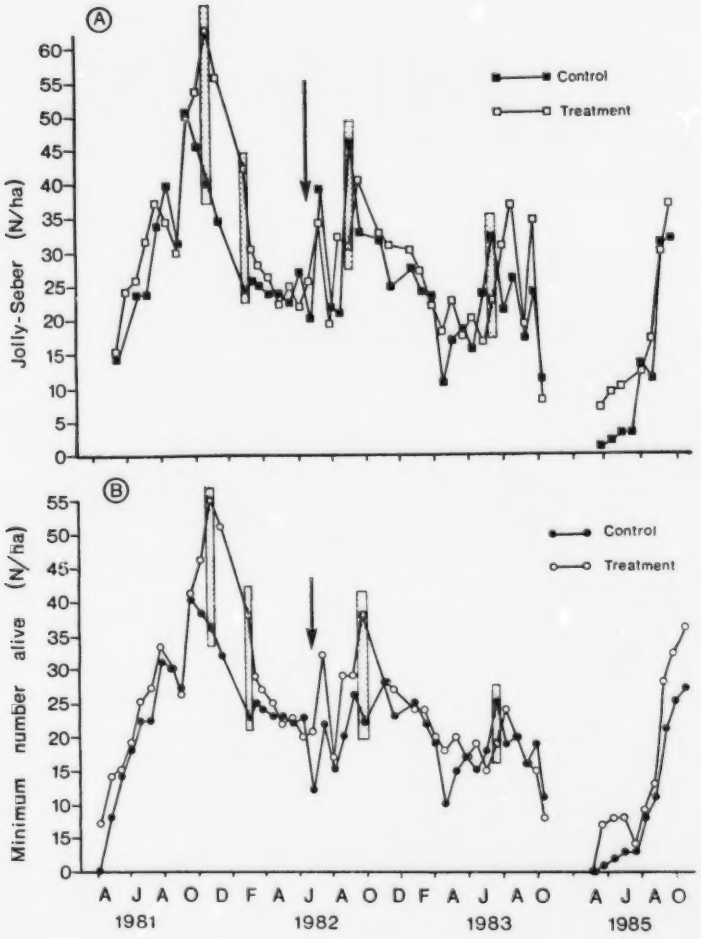

FIGURE 2. Population density (A: Jolly-Seber, B: MNA) of Oregon voles on control and treatment grids during 1981 to 1985. Vertical arrow indicates when glyphosate herbicide was applied to the treatment area. Shaded bars represent specific sampling periods which have significant differences in density of voles between areas.

To rigorously assess the influence of herbicide use on small mammals, three treatment and three control areas should be chosen in a given subzone. These areas should correspond to post-harvest physiognomic stages: herb, shrub, and tree. Post-harvest vegetation changes through time, and with it, the habitat for small mammals. For example, 3-year-old clearcuts are usually dominated by herbaceous vegetation (Gashwiler 1970; Stickney 1982), and herbicides are used for brushing and weeding. By 9 years post-harvest, shrubs and other woody vegetation usually dominate the site (Dyrness 1973; Stickney 1982). Herbicides are then used for brushing and weeding or conifer release. At 15 years post-harvest, multi-storied vegetation has developed, including deciduous trees, shrubs and herbaceous plants (Pollack *et al.* 1986). Herbicides at that stage are used for conifer release. These intervals broadly correspond to the three major complexes of competing vegetation identified by Conard (1984), namely herbaceous dominated, shrub dominated, and tree dominated.

Each study area should be at least 20 ha and include both treatment and control sites within a given block, or if separate, on adjacent blocks. Control and treatment sites on separate blocks must

have similar environmental conditions (e.g., slope, aspect, elevation, seral stage, logging history). Three replicates of each control and treatment physiognomic stage would be ideal.

If possible, sampling units should be established before herbicide application so that pre-treatment data are available.Monitoring should be conducted for at least 4 years to provide adequate data on all species of small mammals. For example, because of cyclic fluctuations in vole abundance, there may be insufficient vole numbers on a given study area during certain years to allow herbicide impacts to be assesed. As well, the snowshoe hare population cycle peaks every 9 - 11 years. Therefore, hares should also be sufficiently abundant before their responses to habitat alteration can be assessed.

4.3.5 Data collection

After the pre-baiting period, rodent traps should be baited with peanut butter and whole oats, and supplied with coarse brown cotton for bedding. Hare traps should be baited with a slice of apple and alfalfa cubes. Traps on grids should be set the afternoon of day 1, checked on the morning and afternoon of day 2 and the morning of day 3, and then locked open between trapping periods. Trapping should continue for additional nights (and traps checked each morning and afternoon) for the longer four - to six - night period required for index lines.

All animals captured should be identified to species. All species of rodents (and insectivores if necessary) can be identified in the field by a trained observer, and this skill passed on to other workers. All animals captured should be ear-tagged with serially numbered fingerling fish tags, sexed, and weighed on Pesola spring balances. Toe-clipping is another means of marking animals but results in reduced survival (Pavone and Boonstra 1985) and is intractable with large numbers of animals. The duration of the breeding season is determined according to the palpation of testes (scrotal or abdominal) for males and the condition of vaginal openings (perforate or not) and mammaries (large or small), and whether or not obviously pregnant for females.All animals should be released at the point of capture after data collection.

For example, all animals captured on the morning check of day 2 are tagged if newly captured, or if already tagged, the number is recorded. The other measurements for that animal are then made and recorded. In the afternoon check of day 2, data are collected from those animals not caught in the morning check. In the morning check of day 3 (and subsequent days on index lines), data are collected from those animals not caught previously. Animals captured on previous checks are called recaptures and their tag number and station only need be recorded.

4.3.6 Data analysis

The most commonly used measurements of density from mark and recapture sampling for a given rodent species are:

1. number of individuals caught;
2. minimum number alive (Krebs 1966); and
3. Jolly-Seber probabilistic population estimate (Jolly 1965; Seber 1982).

The first measurement is a count based on the individuals captured in a given sampling period. The minimum number alive is a count based on the individuals captured in a sampling period, plus those known to be alive because of subsequent capture. This measurement requires that 70 - 80% of animals present are captured in each sampling period (Appendix 2). The Jolly-Seber method is an estimate of density based on the ratio of marked to unmarked captures in a sequence of capture periods. It may be used when less than 70% of animals are captured in each sampling period (Appendix 2).

All three methods are designed for data collected over at least two and preferably several consecutive sampling periods. The minimum number alive and Jolly-Seber methods provide the most accurate and reliable density measurements over time.Nichols and Pollack (1983) have discussed the relative merits of the enumeration method and the probabilistic Jolly-Seber model. Otis *et al.* (1978) provide a further review of population estimation techniques.

In addition to density, several other population parameters are gained by mark and recapture sampling and are summarized by computer programs (available for use from the University of British Columbia). These parameters include proportion of male and female animals in breeding condition, survival rates, age classes of animals, body weights, growth rates, male:female ratios, and movements or range length. All of these parameters are available from the sample of animals captured in each trapping period.

4.3.7 Vegetation and micro-habitat monitoring

Vegetation monitoring is necessary for accurate interpretation of small mammal response to herbicide treatment and should be conducted at each sampling unit. Monitoring should document variations in plant abundance and diversity, and canopy or cover characteristics. These parameters influence habitat suitability for small mammals and are affected by herbicide use.

Monitoring could be conducted in the following manner. A 25-m transect, consisting of five 5 x 5m plots, is established in each treatment and control area. Each plot contains three sizes of nested sub-plots: a 5 x 5m sub-plot for sampling trees; a 3 x 3m sub-plot for sampling shrubs; and a 1 x 1m sub-plot for sampling herbaceous species (Figure 3). Tree, shrub, and herb layers are subdivided into height classes (Table 2). A visual estimate of percent cover is made for each species/layer and species/height class combination within the appropriate nested sub-plot. Total percent cover for each layer and height class and for all layers combined is also estimated. In addition, distribution and vigour codes (Walmsley *et al.* 1980) could be recorded for each species layer.

To facilitate efficient monitoring, field personnel should be familiar with regional vegetation. Monitoring should be conducted in late summer, at the height of vegetation growth. At a minimum, it should be conducted the year preceding herbicide treatment and the first, second, and fifth growing seasons following treatment. Ideally, monitoring would be conducted annually for several years following treatment. This would allow vegetation response to be examined during the period in which a free-standing coniferous plantation was established.

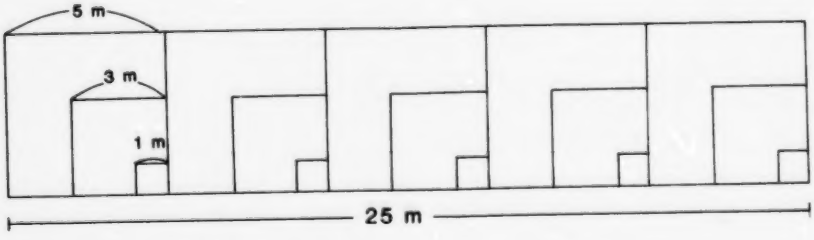

FIGURE 3 Layout of transect and nested subplots for vegetation monitoring

Post-harvest debris may also be an important habitat variable for small mammals on control and treatment areas. Dead and downed woody material, including logs, is widely accepted as an important part of forest habitat (Maser *et al.* 1979). Measurements of this micro-habitat component could follow the methods of Hayes and Cross (1987).

5 CONCLUSIONS

Concerns about the impact of forest herbicides on small mammal populations can only be addressed through a field monitoring program. Monitoring is required to allow researchers to assess the impact on small mammals of habitat alteration resulting from herbicide treatment. It could be conducted in a comprehensive "case study" approach, or as a component of other herbicide-related research. Ideally, it should be carried out in several ecological settings at a variety of stand ages for a period of several years following herbicide treatment. This approach would help identify conditions where small mammals are most affected by habitat alteration. In addition, these studies could improve the general knowledge of small mammal ecology (from control block studies) and small mammal damage to coniferous plantations. The final outcome will be a more enlightened, and possibly more efficient, use of herbicides in intensive forest management.

TABLE 2. Height class categories and corresponding layer classes (after Walmsley *et al.* 1980) (all heights in m)

Tree layer				Shrub layer			Herb layer		
Layer	Tree class	Height class	New symbol	Layer	Height class	New symbol	Layer	Height class	New symbol
A0	veterans								
A1	dominant	30	T1						
A2	main canopy	20 – 30	T2						
A3	suppressed	10 – 20	T3						
B1	2 – 10m	5 – 10	T4						
		3 – 5	T5						
B2	2m	2 – 3	T6		2 – 3	S2		2 – 3	H1
		1 – 2	T7		1 – 2	S3		1 – 2	H2
		.5 – 1	T8	B2	.5 – 1	S4	C	.5 – 1	H3
		.25 – .5	T9		.25 – .5	S5		.25 – .5	H4
		.25	T10		.25	S6		.25	H5

6 INFORMATION AND RESEARCH NEEDS

1. Long-term studies of vegetation response to herbicide treatment in the target subzones is needed. Information is required on responses of the overall vegetation community, and on subsequent succession.
2. Small mammal response to reduced availability of plant products (and browse for hares) and its relationship with feeding damage to crop trees should be examined.
3. The regional and zonal (biogeoclimatic) requirements of local small mammal species, and the flexibility of these requirements, should be examined.
4. The impact of herbicide treatment on habitat use by furbearers requires investigation. Research is also needed to assess the impact of shifts in small mammal community composition on furbearer diet, which may occur following habitat alteration.
5. The potential direct effects of herbicide ingestion on small mammals and the connection of these effects to higher trophic levels, such as furbearers, should be investigated.

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APPENDIX 1. Summary of published studies measuring the responses of major small mammal species to herbicide-induced habitat alteration in several forest types across North America[a]

Author	Study area	Census method	Deer mice	Voles	Chipmunks	Shrews	Total
Black & Hooven (1974)	Coastal forest (Oregon)	Multiple	+	—	0	(+ —)	0
Kirkland (1978)	Spruce & hardwoods (Virginia)	Limited	+	—		+	+
Savidge (1978)	Jeffrey pine (California)	Limited	0		+		+
Borrecco *et al.* (1979)	Coastal forest (Oregon)	Multiple	+	—		(+ —)	—
Sullivan& Sullivan (1982a)	Coastal forest (B.C.)	Intensive	0	0	0	0	0
Anthony & Morrison (1985)	Coastal forest (Oregon)	Multiple	0	+	0	0	0
D'Anieri *et al.* (1987)	Spruce-fir (Maine)	Limited	0	—		0	0
Ritchie *et al.* (1987)	Coastal forest (B.C.)	Single	—				
Freedman *et al.* (1988)	Spruce-fir (Nova Scotia)	Multiple	0	0		0	0
Sullivan (1989)	Coastal forest (B.C.)	Intensive	0	0	—	0	0

[a] 0 no difference, + increase, — decrease.

APPENDIX 2. Measurements of density

Both population estimates and counts may be obtained from mark and recapture sampling. Estimates are based on the ratio of marked and unmarked captures. Counts rely on the number of individuals of a given species caught in each sampling period.

Five assumptions are made by mark and recapture sampling:

1. Animals do not lose their tags (marks).
2. Captures are correctly recorded as marked or not marked.
3. Marking does not affect probability of survival.
4. There is no gain or loss of individuals during the sampling period.
5. The population is randomly sampled so every animal has the same probability of capture.

Failure to meet any of these assumptions invalidates density estimates made from mark and recapture sampling. Two density measurements discussed in the text are expanded upon here.

The minimum number alive (MNA) is one density measurement.

It holds that if a certain number of animals captured at time t are not caught at t + 1, but are recaptured at t + 2, then these animals are alive but not counted at t + 1, and so should be included in the density estimate for that time. For example, if in week 1 (t=1), 15 mice are tagged; in week 4 (t=4), 10 of these tagged mice from week 1 are recaptured plus 4 new mice; and in week 7 (t=7), 14 mice are captured of which 4 were caught in week 1 but not in week 4, then these 4 mice should be added to the MNA total for week 4. Therefore, the MNA at week 4 is 18.

The MNA calculation is based on the assumption that 70-80% of the animals on a grid are captured at each sampling time. To test this assumption, we need to measure trappability of animals in a given population. Minimum unweighted trappability is measured by the following:

$$\text{Trappability (\%)} = 100 \sum_{i=1}^{n} \frac{\text{Number caught at time i}}{\text{Number known to be alive at time i}}$$

where n = number of sampling periods.

This estimate has little bias because initial and last captures are eliminated, and hence all animals caught only once or twice.This estimate of trappability provides only one value for each individual regardless of how long it lives, and is not influenced by animals with long capture histories. If trappability is less than 70%, then the Jolly-Seber population method should be used.

The Jolly-Seber method provides an estimate of density for a sequence of sampling periods based on the ratio of marked to unmarked captures. The population estimation (N) for 1 day of marking followed by 1 day of recapture is made by the Lincoln Index:

$N = Mn / m$

where: M = number of marked animals released from the first sample;

n = number of animals in the second sample;

m = number of marked animals in the second sample.

For example, if 20 mice are tagged on the first day of trapping, and 30 mice, of which 15 are marked, are caught on the second day, then the population estimate is:

M = 20

n = 30 $\quad N = (20)(30) / 15 = 40$

m = 15

The Jolly-Seber method calculates this type of estimate over several consecutive sampling periods by estimating the number of marked animals in the population. The Jolly-Seber formula for population size (N) at time i is:

$N_i = n_i M_i / m_i$

where $M_i = m_i + (n_i Z_i S_i) / m_i r_i$

$(i = 2, ..., k-1)$

where samples are taken on k occasions and the population size is estimated at time i and where:

$M_i =$ estimated number of marked animals in the population at time i;

$Z_i =$ number marked before the ith sample which are not caught in the ith sample but are caught subsequently;

$S_i =$ number released from the ith sample;

$r_i =$ number of the S_i that are caught subsequently;

$k =$ number of sampling periods.

For example, at the fourth sampling period, if:

$n_4 = 30$; $m_4 = 15$; $M_4 = 18.6$, then

$N_4 = (30)(18.6) / 15 = 37.2$

APPENDIX 3. Research and field personnel contacted during the study

Key Research Personnel

Robert Anthony	Oregon Cooperative Wildlife Research Unit Oregon State University Corvallis, Oregon 503-754-4531
Dan Campbell	USDA-APHIS Forestry Sciences Laboratory Animal Damage Control Olympia, Washington 206-753-9450
Wayne Coombs	Canadian Forestry Service Pacific Forestry Centre Victoria, B.C. 604-388-0600
Alton Harestad	Dept. of Biological Sciences Simon Fraser University Burnaby, B.C. 604-291-4809
Hamish Kimmins	Dept. of Forest Sciences University of British Columbia Vancouver, B.C. 604-228-3549
Charles Krebs	Institute of Animal Resource Ecology University of British Columbia Vancouver, B.C. 604-228-4595
Art Martell	Canadian Wildlife Service Delta, B.C. 604-666-0143
Chris Maser	U.S. Bureau of Land Management LaGrande, Oregon 503-757-4419
Michael Morrison	Dept. of Forestry and Resource Management University of California, Berkeley, California 415-642-5344
David Nagorsen	B.C. Provincial Museum Victoria, B.C. 604-387-2933
Jim Rochelle	Environmental Forestry Research Weyerhaeuser Co. Tacoma, Washington 206-924-6324
Larry Taylor	Monsanto Canada Inc. Delta, B.C. 604-943-0119

Mike Wan	Environmental Protection Service Environment Canada West Vancouver, B.C. 604-477-3863
Susan Watts	Department of Forest Sciences University of British Columbia Vancouver, B.C. 604-228-6316

Ministry of Environment

Victoria	
Ralph Archibald	Wildife Branch, Furbearer Biologist 387-9799
Julia Beatty	Fisheries Branch, Pesticide Biologist 387-9766
Vancouver Island Region 1	
Doug Janz	Wildife Biologist, Nanaimo 755-3951
Karen Morrison	Wildlife Biologist, Nanaimo 755-3951
Lower Mainland Region 2	
Glen Carlson	Habitat Technician, Surrey 584-8822
Dave Dunbar	Wildlife Biologist, Surrey 584-8822
Bob Forbes	Wildlife Biologist, Surrey 584-8822
Cariboo Region 5	
Marty Beets	Habitat Biologist, Williams Lake 398-4562
Daryll Hebert	Wildlife Biologist, Williams Lake 398-4564
Omineca Region 7	
Bill Arthur	Habitat Technician, Prince George 565-6425
Dave King	Habitat Biologist, Prince George 565-6422
Glen Watts	Wildlife Biologist, Prince George 565-6426
Skeena Region 6	
Allan Edie	Habitat Biologist, Smithers 847-7288
Jorma Jyrkkanen	Habitat Technician, Terrace 638-3279
Doug Steventon	Wildlife Biologist, Smithers 847-7274

Ministry of Forests

Victoria	
Henry Benskin	Manager, Silviculture Research 387-3179
Vancouver Forest Region	
Gene McInnes	Silviculture, Zone Co-ordinator, Chilliwack District 794-3361
John McClaron	Campbell River District Silviculturist, 286-3282
Mel Scott	Regional Stand Tending Co-ordinator 660-7579
Cariboo Forest Region	
Jane Perry	Regional Stand Tending Co-ordinator 398-4400
Prince George Forest Region	
Les Herring	Regional Silviculturist 565-6186
Angus McLeod	Regional Pedologist 565-6141
Rob Oden	Silviculture, Prince George West District 565-6295
Bruce Pamplin	Regional Stand Tending Co-ordinator 565-6179
Rick Selman	Silviculture, Prince George East District 562-4121
Prince Rupert Forest Region	
Mike Klassen	Morice District Silviculturist, 845-7712
Fred Newhouse	Regional Stand Tending Co-ordinator 847-7514

Jim Pojar	Regional Ecologist 847-7430
John Pollack	Regional Research Officer 847-7436

Trapper's Association

Jim Hatler	B.C. Trappers' Association (Victoria) 604-477-3863
Wayne Sharp	Trappers' International (Prince George) 604-561-1602
Jim Tuck	MacKenzie Trappers' Association (MacKenzie) 604-997-3310

Forest Industry

Merideth Spike	Northwood Pulp and Timber Ltd. (Prince George) 604-962-9611
Gerald Whalley	MacMillan Bloedel Ltd. (Kelsey Bay) 604-282-3331